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A SPREADSHEET (LOTUS 1-2-3) BASED TECHNIQUE FOR ANALYSING STORM SUSPENDED SEDIMENT DATA WITH PARTICULAR REFERENCE TO LOGGING DISTURBANCE IN TROPICAL FORESTS

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ABSTRACT

The procedure describes a simple and functional method using a commercial spreadsheet (Lotus 1-2-3) to calculate water and sediment yields from measured or given data sets. Suspended sediment concentrations are located on a storm hydrograph and concentrations for unsampled points on the hydrograph are estimated using the principle that the change in concentration between two sampled points will be proportional to the change in discharge between the same two points. The relationships are then solved by a cross-correlation equation using simple formulae in the form of triangle–square equations to calculate water and sediment yields between each sample time. The technique is applied to a 51 month data set from a long-term monitoring programme assessing the impacts of commercial logging operations in Sabah, East Malaysia. Yields for the monitoring period derived by the spreadsheet technique are compared with results from the application of more traditional discharge-sediment rating techniques. In the undisturbed catchment, yields derived from some rating equations compare favourably with the spreadsheet technique. However, in the disturbed catchment, rating techniques proved less applicable because of the continuously changing nature of the catchment in relation to vegetation recovery, exacerbating variation and scatter in the data set. The application of the spreadsheet technique provides detailed information at an individual storm level; however, working with the method on long-term discharge records requires a significant commitment of time as compared to the straightforward application of rating equations. © 1998 John Wiley & Sons, Ltd.

KEY WORDS: suspended sediment yields; spreadsheet analysis; storm hydrograph; tropical forest disturbance

INTRODUCTION

This paper aims to provide basic guidance on storm-based suspended sediment load calculations for researchers, students and reseach technicians by improving the accuracy of sediment data analysis with a low-cost PC spreadsheet technique. The calculation of monthly, annual and longer-term suspended sediment yields is often bedevilled by the complexity of hysteresis effects during storm events (Figure 1). Such examples, particularly in small catchments, clearly demonstrate that stream stormwater discharge and sediment concentrations are non-linearly related (see, for example, Walling and Webb, 1988; Douglas *et al*., 1992). Often the reliability of such curves is improved by separating samples collected on rising and falling stages, summer and winter months or dry and wet seasons, to estimate loads of streams (e.g. Malmer, 1990; Balamurugan, 1991). Nevertheless many researchers, often due to operational constraints, use suspended concentrations estimated from discharge rating curves even though the idea of a constant relationship between suspended sediment concentration and discharge is inapplicable. This is especially true in catchments where land use or land cover is changing through time, for example with deforestation. With the authors' work in Ulu Segama, Sabah, East Malaysia, the application of standard and modified rating curve techniques led to large errors for a small, selectively logged catchment (Greer *et al*., 1995). In such an environment, potential erosion sites

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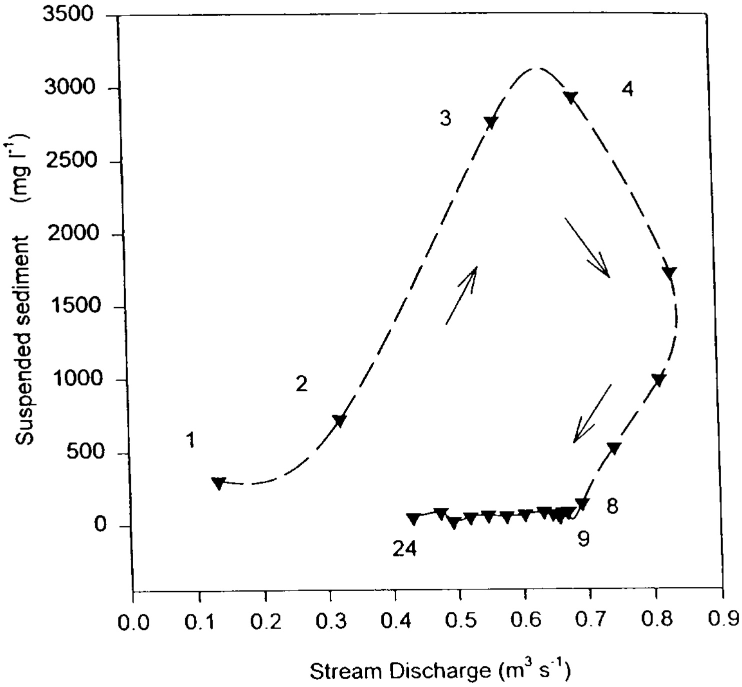

Figure 1. Discharge-suspended sediment concentration plot for the data set presented in Table I. Sample number 10 has been excluded and would probably be rejected from the data set as being anomalous. The hysteresis pattern shows a marked decrease in suspended sediment concentrations on the falling limb of the hydrograph

continually change with the post-logging vegetation recovery. The following technique was adopted to improve the suspended sediment yield estimates for changing environments; however, potential users must still compare and offset time and effort with the more traditional rating curve method.

ANALYTICAL PROCEDURES

The analysis involves three main steps: (1) to locate the time of suspended sediment sampling precisely on the hydrograph; (2) to calculate unsampled water discharge or water level values and sediment concentrations between actual data points; and (3) to calculate the total water discharge and total sediment load for any given time period.

Suspended sediment concentrations expressed as milligrams per litre (mg l^{-1}) were obtained from water samples collected by an automated pumping sampler activated by a float-switch set at a predetermined height above the baseflow level in a stream. Once actuated, the sampler takes 24 samples at predetermined time intervals (7·5 min in this example), sufficient to cover the rising and falling stages of the storm hydrograph generated from the example catchment (Table I). The hydrograph parameters derived from the water level recording device, which in this example was a continuously logging shaft encoder system, are time in Julian days and water level in metres. The float switch was set against stream water level, therefore the suspended sediment data are fitted against water level instead of discharge. Although this could equally be applied to discharge, the quantities involved in water level are easier to manipulate.

In this paper, the Lotus 1-2-3 spreadsheet is used as an example for the calculations. However, any other computer spreadsheet could be used as long as the principal analytical procedures are followed.

Step 1: Locating suspended sediment sampling times on the hydrograph data set (Lotus 1-2-3 spreadsheet)

(a) Load the hydrograph data file into the spreadsheet (Lotus 1-2-3). It is advisable to graph the hydrograph values to ensure that the data set is complete.

Table I. The storm-generated suspended sediment data set obtained by automatic pumping sampler.

	A	B	C	D	E	F	G
1	Gauging station:		Stn. Baru (catchment logged in April–Sept (1989)				
2	Sampling interval:		7.5 min				
3	Float switch level:		22 cm of the water level at stilling well				
4	Date of storm:		9 January 1993				
5	Total daily rainfall		84 mm				
6							
7							
8	Sample number			Suspended sediment concentrations			
9					(mg l^{-1})		
10							
11	1				302		
12	2				721		
13	3				2757		
14	4				2927		
15	5				1719		
16	6				985		
17	7				520		
18	8				138		
19	9				80		
20	10				776		
21	11				81		
22	12				79		
23	13				69		
24	14				49		
25	15				no data		
26	16				66		
27	17				81		
28	18				64		
29	19				52		
30	20				58		
31	21				46		
32	22				17		
33	23				79		
34	24				45		
35							

(b) Arrange the data with relevant column titles within the spreadsheet as shown in Table II.

(c) On the water level (stage) column, identify the float switch level. This may not fall on any of the existing hydrograph data points. For example, the float switch for the sediment data set used here was at 0·22 m. This falls in between row 5 and row 6. If this occurs, insert a blank row and insert the float switch value in the new empty cell (C6).

(d) Calculate the float switch time for the empty cell (B6) produced by step 1c. This is done by using a cross-relationship equation based on the principle that the ratio of the increments in water level from cell C6 to C5 and from C6 to C7 are equivalent to the ratio of increments of time from cell B6 to B5 and from B6 to B7. This relationship should read as:

$$\frac{B6-B5}{B6-B7} = \frac{C6-C5}{C6-C7} \tag{1}$$

By cross-relationship the formula derived is:

Table II. Example of the storm hydrograph spreadsheet layout with suggested arrangement of the data set, columns and titles

	A	B	C	D	E	F	G	H
1	Remarks	Time	Stage	Sediment	Point	Point	Block	Block
2		(Julian days)	(m)	(mg l^{-1})	discharge	sediment	discharge	sediment
3					($m^3 s^{-1}$)	discharge	(m^3)	(G)
4						(g s^{-1})		
5		9.36111	0.173					
6		9.37083	0.27					
7		9.37986	0.403					
8		9.39236	0.459					
9		9.39305	0.454					
10		9.39375	0.461					
11		9.40556	0.435					
12		9.41319	0.429					
13		9.425	0.43					
14		9.43403	0.425					
15		9.44167	0.429					
16		9.45139	0.426					
17		9.46528	0.411					
18		9.48056	0.394					
19		9.48195	0.389					
20		9.48403	0.393					
21		9.49167	0.378					
22		9.49583	0.375					

(B6–B5)(C6–C7) = (B6–B7)(C6–C5)
B6*C6–B6*C6+B5*C7 = B6*C6–B6*C5–B7*C6+B7*C5
B6*C6–B6*C7–B6*C6+B6*C5 = –B7*C6+B7*C5+B5*C6–B5*C7
B6*(C6–C7–C6+C5) = B7*(–C6+C5)+B5*(C6–C7)
B6*(C5–C7) = B7*(–C6+C5)+B5*(C6–C7)

Therefore

B6 = [B7*(C5–C6)+B5*(C6–C7)]/(C5–C7) (1.2)

or

[B7*(C6–C5)+B5*(C7–C6)]/(C7–C5) (1.3)

(e) Obtain the numerical value for Equation 1.3. Put the cursor on row seven. Insert 24 rows (row 7 to row 30). The number of rows to be inserted depends on the number of samples for which suspended sediment concentrations are available.

(f) At B7, add the sample interval time to float switch time cell (cell B6) to calculate the exact time for the first sample. It must be remembered that the time unit for the hydrograph is Julian days, therefore, interval time must be in the same units. This is equivalent to 7·5 min divided by the number of minutes in a day (7·5/1440 = 0·005208). The B7 cell formula should now read as: B6+0·005208. Copy this cell to the rest of the inserted rows in column B (copy cell B7 to B8 . . . B30). Convert all the cell formulae to values (Table III).

(g) Input the suspended sediment concentration data in column D. Sample no. 1 should be at cell D7 (7·5 min or 0·005208 Julian days after the float switch actuated the automatic pumping sampler). The other sample numbers should be placed in the following cells in order. It is useful to type the actual sample numbers in column A (Table III).

(h) Sort the appropriate spreadsheet data set to place all the added data points in the correct order. In Lotus 1-2-3 the Data-Sort commands are used. For this example the Data-Range is from A5 to end of the file whilst the

Table III. Arrangement of the spreadsheet after the first sample time has been identified. The sediment data set has been inserted but not yet sorted

	A	B	C	D	E	F	G	H
1	Remarks	Time	Stage	Sediment	Point	Point	Block	Block
2		(Julian days)	(m)	(mg l^{-1})	discharge	sediment	discharge	sediment
3					(m^3 s^{-1})	discharge	(m^3)	(G)
4						(g s^{-1})		
5		9.36111	0.173					
6	f/s	9.36581	0.22					
7	1	9.37102		302				
8	2	9.37623		721				
9	3	9.38144		2757				
10	4	9.38665		2927				
11	5	9.39186		1719				
12	6	9.39706		985				
13	7	9.40227		520				
14	8	9.40748		138				
15	9	9.41269		80				
16	10	9.4179		776				
17	11	9.42311		81				
18	12	9.42832		79				
19	13	9.43353		69				
20	14	9.43874		49				
21	15	9.44395		no data	(this row may be deleted)			
22	16	9.44915		66				
23	17	9.45436		81				
24	18	9.45957		64				
25	19	9.46478		52				
26	20	9.46999		58				
27	21	9.4752		46				
28	22	9.4804		17				
29	23	9.48561		79				
30	24	9.49082		45				
31		9.37083	0.27					
32		9.37986	0.403					
33		9.39236	0.459					
34		9.39305	0.454					
35		9.39375	0.461					
36		9.40556	0.435					
37		9.41319	0.429					
38		9.425	0.43					
39		9.43403	0.425					
40		9.44167	0.429					
41		9.45139	0.426					
42		9.46528	0.411					
43		9.48056	0.394					
44		9.48195	0.389					
45		9.48403	0.393					
46		9.49167	0.378					
47		9.49583	0.375					

Primary-Key must be at column B (time), that is B5 to the end of the file (Table IV). The Time-Sort order is Ascending.

Step 2: Calculating the unsampled suspended sediment concentrations and water level values (Table IV)

Modification of Equation 1.3 (step 1d) should be applied. The basic principle involved in this procedure is to estimate missing values from the nearest existing data points. Estimated data points would be linearly related to their corresponding variables: water levels to time; sediment concentrations to water levels.

It is practical to first calculate the unsampled water level values before sediment values as the later estimations of sediment concentration are based on the water level. When the number of empty cells (unsampled points) is greater than one, it is also practical to first calculate the cells with the highest values for which data are missing. The next cells should then be calculated using the last calculated values as the new nearest data points. When this rule is followed, the next unsampled cells can be calculated by copying the appropriate formulae from the previous calculated gap.

(a) Water level-time calculations: for example to illustrate how a gap of three or more cells would be treated. The unsampled water level gap comprising cells C11 to C13 (Table IV) should be calculated in the manner of the first cell C13, followed by cell C12 and C11 accordingly. Formulae for those cells should read:

    C11 = [B12*(C11–C10)+B10*(C12–C11)]/(C12–C10)
    C12 = [B13*(C12–C10)+B10*(C13–C12)]/(C13–C10)
    C13 = [B14*(C13–C10)+B10*(C14–C13)]/(C14–C10)

    Note that the preceding gap comprising the two empty cells C8 and C9 (Table IV) can be calculated by copying the formulae cells C11 . . . C12 to C8 . . . C9. Similarly, cells C17, C18 and C19 can be calculated by copying cells C11 . . . C13 to C17 . . . C19. It should be remembered that the cells copied must start from the first formulae of the already calculated gap and this should be copied to the first cell of the next empty cell gap.

(b) The sediment concentrations–water level relationship. Calculation of unsampled suspended sediment concentrations should follow the same basic procedure as step 2a. The appropriate cells of water level formulae in column C of the spreadsheet can be directly copied to the unsampled sediment concentration gap in column D. For example cell D10 (Table IV) can be calculated by copying the formula in cell C11, thus cell D10 should automatically read:

    [C11*(D10–D9)+C9*(D11–D10)]/(D11–D9)

    Similarly, the gap that comprises of cells D14 . . . D16 can be calculated by copying cells C11 . . . C13.

Step 3: Calculating total water and suspended sediment yields

The complete extrapolation of unsampled water level and suspended sediment concentration data points (Table V) permits the calculation of water and suspended sediment yields for any desired duration. However, the example given here only calculates the yields for the duration of 3 h, i.e. from 7·5 min after the float switch was onset to the last pumped sample of the storm runoff. Complete storm yields of water and sediment or even daily, weekly and monthly values can be easily calculated by carefully following and understanding the procedures explained above. However, the reliability of the extrapolations is dependent upon the original data points and therefore a well planned sampling programme is required, including manual sampling at baseflows and immediately before and after storm runoff events. Such a situation is usually only possible in well staffed, small catchment studies.

(a) Type the water discharge (Q)–water level rating curve equation in column E to calculate the Q points (in $m^3 s^{-1}$) for each water level data point.
(b) In column F multiply values in column E (Q data points) with those in column D (suspended sediment concentrations) to obtain the suspended sediment transport rate ($mg\,l^{-1} \times m^3 s^{-1} = g\,s^{-1}$).
(c) In column G calculate the total discharge (Q) between rows of data points using triangle–square equations. For example, in column G row 9 (G9), the equation should read:

Table IV. Data organization in the spreadsheet after sorting and before the calculation of missing stage and sediment data

	A	B	C	D	E	F	G	H
1	Remarks	Time	Stage	Sediment	Point	Point	Block	Block
2		(Julian days)	(m)	(mg l^{-1})	discharge	sediment	discharge	sediment
3					($m^3 s^{-1}$)	discharge	(m^3)	(G)
4						(g s^{-1})		
5		9.36111	0.173					
6	f/s	9.36581	0.22					
7		9.37083	0.27					
8	1	9.37102		302				
9	2	9.37623		721				
10		9.37986	0.403					
11	3	9.38144		2757				
12	4	9.38665		2927				
13	5	9.39186		1719				
14		9.39236	0.459					
15		9.39305	0.454					
16		9.39375	0.461					
17	6	9.39706		985				
18	7	9.40227		520				
19		9.40556	0.435					
20	8	9.40748		138				
21	9	9.41269		80				
22		9.41319	0.429					
23	10	9.4179		776				
24	11	9.42311		81				
25		9.425	0.43					
26	12	9.42832		79				
27	13	9.43353		69				
28		9.43403	0.425					
29	14	9.43874		49				
30		9.44167	0.429					
31	16	9.44915		66				
32		9.45139	0.426					
33	17	9.45436		81				
34	18	9.45957		64				
35	19	9.46478		52				
36		9.46528	0.411					
37	20	9.46999		58				
38	21	9.4752		46				
39	22	9.4804		17				
40		9.48056	0.394					
41		9.48195	0.389					
42		9.48403	0.393					
43	23	9.48561		79				
44	24	9.49082		45				
45		9.49167	0.378					
46		9.49583	0.375					

86 400*(B9–B8)*[E8+1/2*(E9–E8)]

where 86 400 is the number of seconds per day.
The above equation calculates the total discharge (Q, in m^3) between row 8 and row 9. Copy this formula to the remainder of column G cells.

Table V. The spreadsheet witth complete calculation of stormwater and suspended sediment yield

	A	B	C	D	E	F	G	H
1	Remarks	Time	Stage	Sediment	Point	Point	Block	Block
2		(Julian days)	(m)	(mg l^{-1})	discharge	sediment	discharge	sediment
3					($m^3 s^{-1}$)	discharge	(m^3)	(G)
4						($g s^{-1}$)		
5		9.36111	0.173		0.02631			
6	f/s	9.36581	0.22		0.06188			
7		9.37083	0.27		0.12825			
8	1	9.37102	0.27291	302	0.13325	40.2415		
9	2	9.37623	0.34962	721	0.32173	231.9673	102.4033	61266.59
10		9.37986	0.403	2518	0.53341	1343.126	134.0996	246999.9
11	3	9.38144	0.41002	2757	0.56761	1564.901	75.15122	198490.3
12	4	9.38665	0.42066	2927	0.69116	2023.025	283.3139	807541.7
13	5	9.39186	0.43675	1719	0.83295	1431.841	343.0345	777593.7
14		9.39236	0.459	755	0.84754	639.8927	36.29858	44749.45
15		9.39305	0.454	972	0.81514	792.3161	49.56117	42691.28
16		9.39375	0.461	668	0.86075	574.981	50.67891	41347.06
17	6	9.39706	0.45369	985	0.81317	800.9725	239.3572	196750.3
18	7	9.40227	0.44222	520	0.74237	386.0324	350.1085	267161.6
19		9.40556	0.435	204	0.7001	142.8204	205.0154	75164.79
20	8	9.40748	0.43348	138	0.69146	95.42148	115.4216	19760.73
21	9	9.41269	0.42938	80	0.66849	53.4792	306.0867	33513.37
22		9.41319	0.429	146	0.66633	97.28418	28.83211	3256.489
23	10	9.4179	0.42939	776	0.66854	518.787	271.6087	125353.2
24	11	9.42311	0.42984	81	0.67099	54.35019	301.4907	128997.1
25		9.425	0.43	81	0.67188	54.42228	109.6426	8881.055
26	12	9.42832	0.42816	79	0.66171	52.27509	191.2688	15302.96
27	13	9.43353	0.42527	69	0.64599	44.57331	294.3267	21797.86
28		9.43403	0.425	72	0.64449	46.40328	27.87437	1965.094
29	14	9.43874	0.42746	49	0.65788	32.23612	264.9958	16000.92
30		9.44167	0.429	54	0.66633	35.98182	167.6132	8634.754
31	16	9.44915	0.42669	66	0.65365	43.1409	426.5331	25567.4
32		9.45139	0.426	69	0.6499	44.8431	126.1419	8514.036
33	17	9.45436	0.42279	81	0.63265	51.24465	164.5563	12328.44
34	18	9.45957	0.41716	64	0.6032	38.6048	278.1552	20222.6
35	19	9.46478	0.41154	52	0.57475	29.887	265.1236	15415.59
36		9.46528	0.411	53	0.57206	30.31918	24.7711	1300.453
37	20	9.46999	0.40576	58	0.54655	31.6999	227.6058	12619.15
38	21	9.4752	0.39996	46	0.51928	23.88688	239.8885	12511.03
39	22	9.4804	0.39417	17	0.493	8.381	227.3986	7248.657
40		9.48056	0.394	20	0.49222	9.8444	6.809841	125.974
41		9.48195	0.389	92	0.47035	43.2722	57.8004	3189.546
42		9.48403	0.393	34	0.48779	16.58486	86.09463	5378.516
43	23	9.48561	0.38989	79	0.47421	37.46259	65.66227	3689.063

(d) In column H the total sediment yield between rows of data points is calculated. The equation should be similar to that in step 3c. Therefore, the equations in column G can be applied to column H by changing E to F (substituting the sediment transport rate for discharge). For example, total sediment load (in g) between row 8 and row 9 data points is calculated by the formula:

86400*(B9–B8)*[F8+1/2*(F9–F8)]

This formula is then copied to the rest of the column H cells.

(e) Finally, calculate the total Q(m^3) and total suspended sediment (g or kg) for the 3 h sampling period. For this example the formulae should read as:

Total Q: @sum (G9 . . . G44)
Total suspended sediment: @sum (H9 . . . H44)

A complete example of the spreadsheet calculation is shown in Table IV.

APPLICATION OF LOTUS 1-2-3 MACROS

The procedures explained above can be compiled into a few personal macro keys, which greatly increases the speed of analysis. For example, steps 1d to 1f can be compiled to a macro key that may be named /T. The basic macro cells may be written as:

‘‘/CG2~	row 1
‘‘/rv~	row 2
‘‘{dl}/wir{?}~	row 3
‘‘+{ul}+(7·5/1440)~	row 4
‘‘/c~{dl}{?}~	row 5
‘‘/rv{?}~	row 6

NB: Make sure that no data are in the macro cell rows.

The macro in row 1 calculates the automatic float switch time by automatically copying the appropriate formula from cell G2; in this example the formula at cell G2 is [G3*(H2–H1)+G1*(H3–H2)]/(H3–H1). Row 2 converts the formula to a value. Row 3 allows the insertion of rows in the spreadsheet by using the up and down cursors. Row 4 is to calculate the first automatic sample time. Row 5 copies the automatic sampling time formula to the following rows as desired by just using the ‘colon’, ‘up’ and ‘down’ cursors. Finally, row 6 is to convert all the formulae to values by using ‘up’ and ‘down’ cursors.

Therefore, by pressing the <Alt> and <T> keys at the float switch time cell, the appropriate places for the suspended sediment concentration data set will be identified and inserted by following the macro prompts. Equally for step 2, several macros keys can be created with respect to how many unsampled data points (empty cells) there are in a particular gap. This can be done by arranging and expanding the formulae used in step 2 and by locating them in a protected cell area of the spreadsheet. The appropriate macros keys are then created to copy the formula cells when the macros are run.

APPLICATION AND VARIATION OF SUSPENDED SEDIMENT RATINGS

Suspended sediment behaviour in two small tropical rain forest drainage basins in Sabah, East Malaysia, was monitored from September 1988 until the end of 1993. The geographical proximity, hydrological similarity and comparable lithologies of the two study drainage basins – Sungai W8S5 (Sg.W8S5; 1·7 km^2) in an undisturbed rain forest conservation area, and Sungai Steyshen Baru (Sg. SB; 0·5 km^2) in a nearby (2 km) logging concession – allowed some comparison of drainage basin response to be made. Sungai Steyshen Baru was selectively logged for commercial timber in November 1988. The treatments also allowed for the comparison of various suspended sediment estimation techniques. As part of an on-going monitoring programme (Douglas *et al*., 1992), suspended sediment was sampled during storm events by float switch-activated automated liquid samplers (*ALS*) and per visit integrated depth (*Grab*) samples which usually coincided with base and lower flow conditions.

Basic suspended sediment-discharge rating equations were derived by grouping the samples by collection method: *ALS*, *Grab* and a combination of both data sets *All*. The suspended sediment ratings were then applied to the continuous discharge record and the computed loads compared to the *Measured* loads (Figures 2 and 3). *Measured* loads were determined by calculating individual storm totals using the spreadsheet technique described above and by integrating values between baseflow and storm samples. The *Measured* data set was considered the most representative of actual stream conditions and was used as a basis for comparison with synthesized loads.

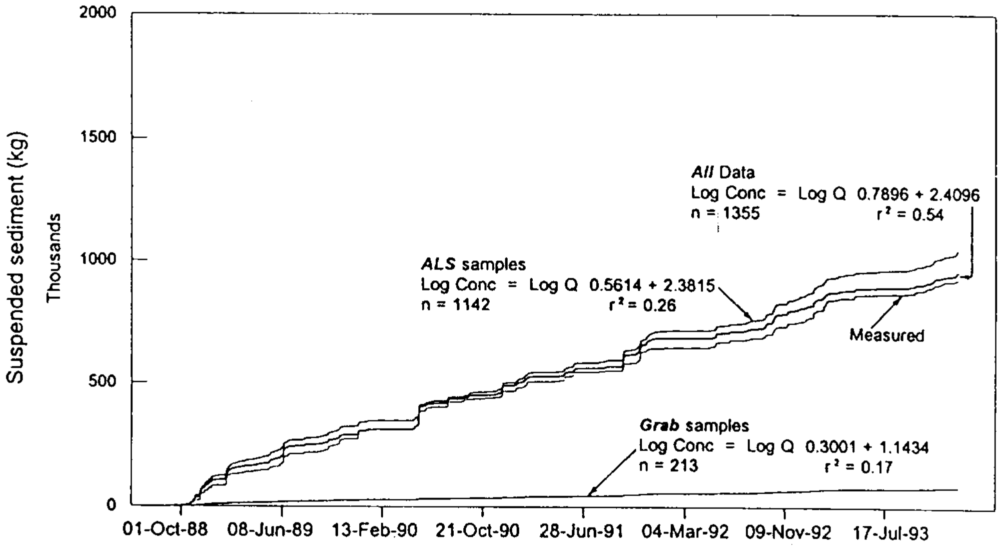

Figure 2. Measured and synthesized cumulative sediment loads for the undisturbed forest catchment, Sg.W8S5

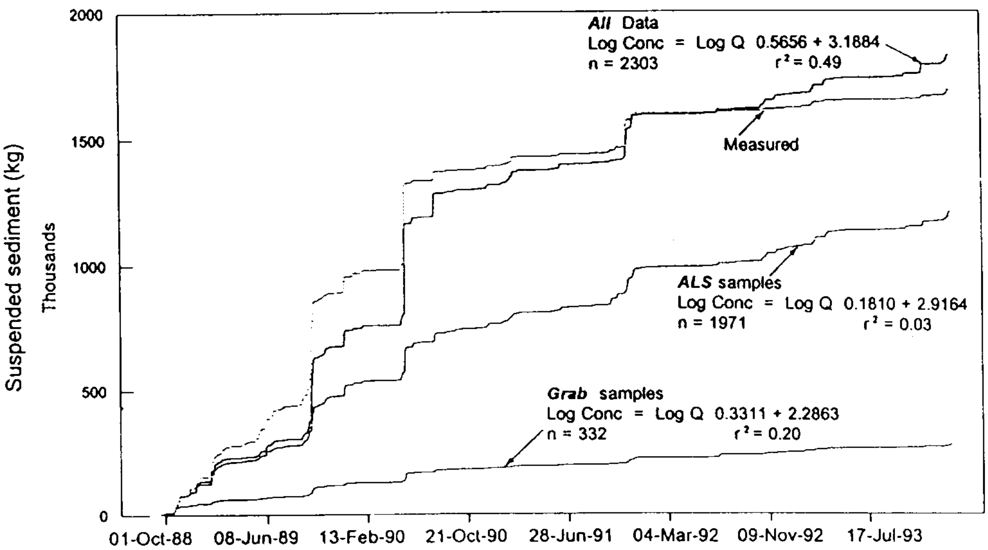

Figure 3. Measured and synthesized cumulative sediment loads for the disturbed forest catchment, Sg.SB

Depending upon the technique applied, over- and under-estimations can be expected as the rating derived from storm samples (*ALS*) will preferentially contain higher suspended sediment concentrations and likewise the *Grab* samples will under-estimate due to the non-storm sample bias. In both catchments the combination of the two sets (*All*) provides the nearest approximation to the measured load as a broad range of discharge values are represented. This is in part reflected by the r^2 values for the *All* data sets: 0·54 for Sg.W8S5 and 0·49 in Sg.SB. It is probable that the *ALS* and *Grab* regression equations for the disturbed catchment and the *Grab* regression for the undisturbed catchment would be rejected due to the poor relationship with discharge.

The poor relationship overall of suspended sediment and discharge is probably due to sediment exhaustion in the undisturbed catchment (Douglas *et al.*, 1992) and the continually changing conditions within the disturbed catchment. The application of a suitable multiple regression analysis may account for increasing amounts of

variation (see, for example, Walling, 1974). For this example, the ratings applied to both drainage basins were not further differentiated by flow or temporal criteria – variables which are important when describing variation in environments adjusting to disturbance (see, for example Grant and Wolff, 1991).

Significant aspects of the disturbed catchment plot are the importance and dominance of the large storm events, particularly during the two years immediately post-logging, and the disparity between the *Measured* and computed sediment loads (Figure 3). The *ALS* and *Grab* sample values both under-estimate particularly during the extreme storm events, which in part accounts for the large disparities in the accumulated plot presentation. Again, much of this discrepancy can be attributed to the lower suspended sediment values towards the end of the period suppressing higher values in the earlier stages of disturbance.

In the undisturbed catchment, although discharge only explains about 50 per cent of the variation for the *All* data totals, the general trends and total volume of sediment are similar to the *Measured* loads with very little overall variation. The exception to this is the *Grab* sample rating which significantly under-estimates all loads apart from during baseflow conditions.

The situation for the disturbed catchment is noticeably different. For all the data sets the general trends are similar, reflecting the partial dependence on discharge, but total yields vary significantly. This is particularly noticeable in relation to the large storm events. The general trend was for the rating techniques to under-estimate loads; however, towards the end of 1991 the cumulative total of the *All* rating yields began to over-estimate when compared to *Measured* totals. Again, this is a reflection of the catchment vegetation recovering and sediment yields declining. The continuously declining sediment concentrations will eventually be reflected in the rating; however, as would be expected, there appears to be a significant lag in response represented by the calculated load totals. Even though sediment production declined with vegetation in the disturbed catchment, there were still occasions, particularly in relation to the continued decay and collapse of logging roads, that produced high volumes of sediment (Greer *et al*., 1995). Sediment influx in this form continued to contribute to the scatter and variation in the ratings. In both drainage basins the possible under-estimation that results from the logarithmic transformation of values (Ferguson, 1986) is masked by a high scatter of values and the inherent variability, in part a result of removing considerable volumes of sediment from temporary storage (Spencer *et al*., 1990).

CONCLUSION

Spreadsheet packages customized with simple macros enable the integration of water level records with storm period suspended sediment data to provide a reliable estimate of total water discharge and suspended sediment load. With the addition of baseflow sediment concentration, data records can be extended for long periods and provide an acceptable and efficient means of assessing hydrological data. The method is particularly appropriate in environments undergoing land-use change which effectively excludes the application of rating techniques. Other river load data such as bedload transport, total dissolved solids, solute loads and organic debris can be analysed in a similar way providing adequate samples are available.

The application of the spreadsheet technique provides detailed information at an individual storm level; however, working with the method on long-term discharge records requires a significant commitment of time as compared to the straightforward application of rating equations. From this example it would appear that overall there is little to be gained over the application of the *All* rating technique, particularly when examining longer-term trends. However, it is also clear that the use of data sets biased towards baseflow or stormflow conditions alone carries with it severe limitations. This is particularly so for disturbed environments.

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